(19) Europäisches Patentamt
European Patent Office
Office uropéen des brevets

(11) Publication number : 0 473 363 A2

(12) EUROPEAN PATENT APPLICATION

(21) Application number : 91307732.7

(51) Int. Cl.[5] : H05K 13/08

(22) Date of filing : 22.08.91

(30) Priority : 31.08.90 US 576304

(43) Date of publication of application : 04.03.92 Bulletin 92/10

(84) Designated Contracting States : DE FR GB IT NL

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(54) Metrology system for analyzing panel misregistration in a panel manufacturing process and providing appropriate information for adjusting panel manufacturing processes.

(57) A metrology system to analyse panel misregistration in a panel manufacturing process includes a software controlled system which checks defined panel parameters on the four corners of a panel and related artwork for processing with a master pettem etched on a glass reference with a machine vision measuring system. The panel or artwork being checked is positioned by panel center registration means to align the center of the panel with the center of the master pattem. Displacement and rotational differences are entered under software control into a data base and analyzed by a stored program intelligent analyses system into a plurality of parameters based on a parameter model which permits an analysis of the cause of the misregistration.

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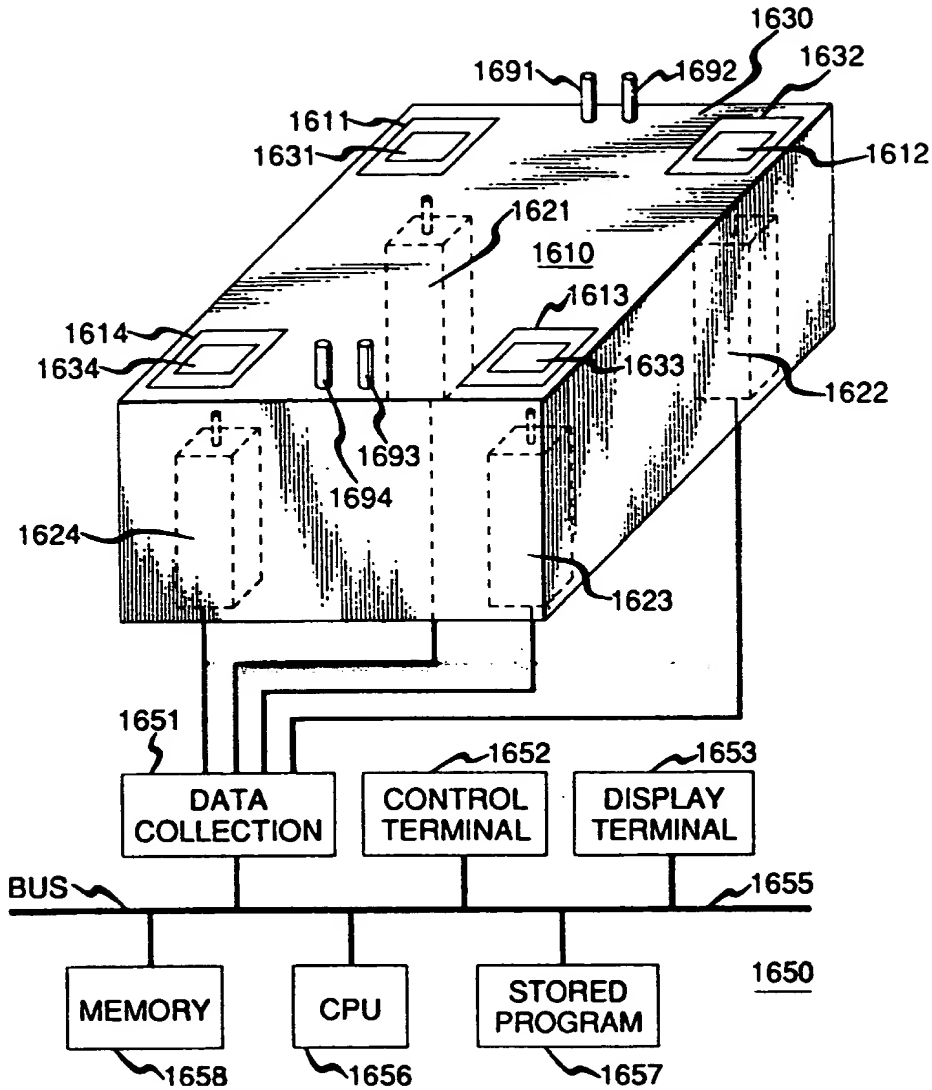
FIG. 16



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DATA COLLECTION
CONTROL TERMINAL
DISPLAY TERMINAL
BUS
1655
1650
MEMORY
CPU
STORED PROGRAM
1658
1656
1657

Field of th Inv ntion

This inv ntion relates to statistical process control of a panel or printedcircuit board manufacturing process. It specifically relates to a metrology system for detecting and correcting process errors causing misregistration of panel components and features.

Background of the Invention

U.S. patent 4,793,052 entitled "Method for Positioning a Panel" discloses a panel locating method operative to engage holes in a panel. These holes are located in the panel symmetrically about a fixed point and axis. The locating method operates by applying synchronized opposing displacements of engaging elements engaging the holes to locate and secure the panel on a work surface.

Summary of the Invention

Therefore, an apparatus and method is provided to analyze pattern registration as claimed in claims 1 and 4.

Brief Description of the Drawing

In the Drawing:

FIGS. 1-8 disclose schematically various panel misalignments and deformations that occur and which may adversely affect registration during panel processing;

FIG. 9 is a schematic of a typical pattern of misregistration;

FIG. 10 is a schematic of illustrative fiducials added to a reference device, the phototool and the panels to facilitate measurement of misregistration;

FIG. 11 is a schematic of a panel or phototool layout and of tooling features included to facilitate positioning of these items for measurement and processing;

FIG. 12 discloses a flowchart of the overall process control used to monitor registration in a panel processing system;

FIGS. 13 and 14 disclose a flowchart of a process to identify probable causes of detected misregistration;

FIG. 15 is a flowchart for performing periodic trend analysis of the panel manufacturing process to identify the probable causes of misregistration; and

FIG. 16 is a schematic of processing tools and supporting equipm nt used in the registration measurement and analysis process control.

Detailed Description

Th manufacture of printed circuit boards or panels with superimposed patterns involves a large number of sequential operations in which a plurality of patterns and tools must be maintained in registration with each other during the manufacturing process from start to finish. During this manufacturing process, various machine tools, phototools and panels must be repeatedly brought into registration with each other. This registration must be repeatedly validated and corrections to the process made when misregistrations of patterns and/or panels occur.

For a manufacturing process to maintain a desired registration accuracy, it must depend on accurate inspection to detect misregistration, followed by the proper corrective action to the manufacturing process. This requires a precise understanding as to the probable causes of the misregistrations occurring. Basic to acquiring this understanding is knowledge of how the panel being processed and the related machine tools and phototools are superimposed during processing and how misalignment and dimensional changes contribute to misregistrations.

Panels, for example, experience dimensional changes due to temperature and/or humidity. Relative dimensional changes between panels and phototool cause misregistration. Errors in setup of tools and machines represent another cause of misregistration. Wear of tools and processing machines over extended periods of time may affect registration. The combined effect of many simultaneously occurring errors masks the individual causes. By defining the misregistration in terms of a physically significant model, the measurements of fiducial displacements may be transformed into parameters which may be manipulated to pinpoint the causes of the misregistration.

Primary parameters of misregistration are graphically depicted in the FIGS. 1-8 which illustrate the various primary categories, established according to the invention, within the eight-parameter model or framework used in the illustrative process monitoring and control system. The eight-paramter model of misregistration is descriptive of how well the patterns on a panel or phototool are registered and is amenable to determining the causes of misregistration. (Patterns on a panel may include drilled holes, copper features or solder mask features, while patterns on a phototool are the opaque features imprinted on the phototool.) The eight parameters are divided, according to the invention, into two primary classes; rigid body displacements and material deformation dimensional changes.

The rigid body displacements are directional shifts and include the x-shift, y-shift and rotati n. A change in a horiz ntal locati n x r x-shift (designated ΔX) is shown in FIG. 1. The central origin 101 of the pattern is displaced ΔX to point 102. Solid line 110

represents th correct alignment and dotted line 111 represents the displaced pattern object. A vertical location chang ΔY or y-shift is sh wn in FIG. 2. Here the actual pattern 211 is displaced froom the solid line reference boundary 210 by ΔY. Both ΔX and ΔY are independent of one another to the extent that a change in one location x or y is not a direct influence on the change in location along the axes y or x, respectively. The pattern and reference center points are shifted away from one another but the shape and area of the pattern remains unaltered.

The third rigid body parameter is shown in FIG. 3. It involves a simple angular change (rotation) Θ of the pattern. If rotation alone occurs, the centers 310 of the pattern and reference are not affected and remain concordant with one another. Rotation often occurs in conjunction with x- and y-shifts.

Deformation parameters are related to changes in the shape and form dimensions of the pattern. Two deformation parameters, shown in FIGS. 4 and 5, are designated as the alpha (α) and beta (β) parameters. Each of these parameters involves a stretch and contraction along the same axis of the pattern but displaced to opposing sides of the pattern as shown in FIGS. 4 and 5. In the alpha distortion, shown in FIG. 4, the top edge 401 has been stretched while the lower edge 402 has shrunk. In the beta distortion of FIG. 5, the left edge 502 has shrunk and the right edge 503 has expanded.

Shear, another deformation parameter shown in FIG. 6, involves a skewing of the vertical axis 601 with respect to the horizontal axis 602. It is symbolically designated γ_{XY} and it results in a deformation of the pattern that causes its shape to depart from a right angled parallelogram.

FIGS. 7 and 8 disclose dimensional changes in the pattern along the x-and y-axis in which the respective pattern and reference centers 701 and 801 are not shifted relative to each other. These changes in dimension are designated ε_X and ε_Y and are normally uniform over the entire pattern. They may be due to temperature and humidity changes or other causes that cause corresponding changes along the x-and y-axis.

These eight primary parameters have been derived from a dimensional analysis of the various changes which may occur to the panel and related phototools and machine tools during various stages of the process. A typical deformation of a panel, for example, is shown in FIG. 9 in terms of change in the coordinate location of its corners 901-904 to the points 911-914. Each corner shift can be defined with a horizontal shift U and a vertical shift V. According to the eight-parameter model, these basic dimensional changes U and V can be defined by a polyn mial series from which it is d rived.

One particular pattern of fiducials used in th illustrative embodiment is shown in FIG. 10 and is discussed below. Given th U and V displacements of the four measured fiducials, the ight parameters are solved from a polyn mial series. Two polynomial series are used to express each U and V displacement in terms of four coefficient values which are selected to describe how one pattern is registered to another in terms that are physically significant. Any displacements between corresponding points on two superimposed patterns are related to combinations of rigid body translations and rotations and to specific types of material deformations of the patterns.

The horizontal displacement U depends on the four values

$$U = a_o + a_1x + a_2y + a_3xy \quad (1)$$

The vertical displacement V depends on the four values

$$V = b_o + b_1x + b_2y + b_3xy \quad (2)$$

The parameters are related to the coefficient terms of the formulas (1) and (2) as follows:

Parameter	ab formula
ΔX, x-Shift	a_o
ΔY, y-Shift	b_o
θ, Rotation	b_1
γ_{XY}, Shear	$b_1 + a_2$
ε_X, X Expansion	a_1
ε_Y, Y Expansion	b_2
α, Alpha	a_3
β, Beta	b_3

Occurrences of misregistrations, in the illustrative embodiment, are detected by the displacements of four fiducials relative to a standard of reference. In the illustrative embodiment the reference fiducials are engraved on a reference glass plate. A schematic of the fiducials used in the illustrative mbodiment is shown in FIG. 10 and comprises the four square mark rs or reference fiducials 1001-1004 engrav d on the reference glass 1000. Th rectangular boxes 1011-1014 overlaid there n represent the fiducials

that are on th phototool or other item and are being compared to the reference fiducials.

The center coordinate point 1010 of the reference is the master reference frame point from which th horizontal and vertical displacements are respectively measured. The reference center 1010 is selected as the controlling reference point in the embodiment herein because it is easy to align with and permits a more uniformly accurate registration over the extent of the panel. Apparatus for aligning panels and phototool to a common center 1010 and a common axis 1020 reference has been disclosed in my prior patent 4,793,052 issued December 27, 1988 which discloses a method for positioning a panel and its phototool. Positioning apparatus engages tooling features (i.e., holes) in the panel to align and secure one panel to a machine reference. The method disclosed therein uses one major axis and a reference origin which is at the panel center. Displacements occuring in panel features are in general smaller than for other positioning systems that use other reference origins because a center origin minimizes the maximum registration error caused by various deformations. Another advantage of this method is the virtual elimination of positioning backlash which detracts from many mechanical positioning schemes. This elimination of backlash in the positioning significantly enhances the performance of the metrology system disclosed herein.

A typical panel layout for processing, as shown in FIG. 11, may include a plurality of individual printed cicuit board layouts 1101-1105 on the panel. These five printed circuit board layouts are positioned as shown on the panel. Tooling features comprising the paired holes 1110 at opposite edges of the panel allow its positioning for processing, as per the methods disclosed in the 4,793,052 patent which is included herein by reference. The metrology system, according to the invention, initially measures the offset of phototool or panel fiducials from reference fiducials. These offsets are convened to parameters of a model of the deformation and rigid position displacements of a single panel. By further converting these offset measurements into a set of advanced parameters, the physical causes of misregistration are identified. Long term trends are identified by analysis of these advanced parameters for aggregates of several lot samples.

The flow diagram of this metrology process is shown in FIG. 12. This may be implemented in a stored program controlled system such as shown in FIG. 16. A lot sample is defined for testing per the instructions of block 1203. The measurement process begins in bl ck 1205 by comparing th registration f the fiducials in the corners of th panel ph totool r tool with th absolute reference fiducials. Th U and V fiducial ffsets in each of the four corners are measured and recorded in a data bas , as per the instructions of bl ck 1205. In the illustrati n this data base is stored in a data processing computing device. These measurements are repeatdly performed until the entire lot sample has been measured as determined by the decision block 1205.

These U and V measurements are convened by the instructions of block 1209 to the eight-parameter model defined by equations (1) and (2) above. The values a_n and b_n are obtained by solving equations (1) and (2). These eight values define the primary parameters of the metrology model as listed above. These primary parameter values are transformed into advanced parameters by the instructions of block 1211. The processes of block 1211, in performing this transformation, are disclosed in detail in the flowchart of FIGS. 13 and 14, and discussed herein below. The various measurements and calculated parameters are used to generate tables and control charts for trend evaluation as per the instructions of block 1213.

The flow process for deriving the advanced parameters and analysing the causes of detected misregistrabons is disclosed in the flowcharts of FIGS. 13 and 14. Initially the offset measurements are read from a data base and converted to the primary parameters by the intrauctions of block 1303. These primary parameter values are used, per the instructions of block 1305, to derive the averages of ΔX, ΔY and Θ which represent the rigid body translations. These averages are designated $\overline{\Delta X}$, $\overline{\Delta Y}$ and $\overline{\Theta}$.

The range and standard deviation are different but statistically proportional measures of the viability within a set of data. Choosing whether to use the standard deviation or the range depends upon the physical requirements of the production process and the level of training of the process operators. The lot range (maximum minus minimum within a lot) is typically used on operator-level control charts. The standard deviation is used for long term trend analysis, which will be described later.

The lot ranges are calculated from the measurements as per the instructions of block 1307. These values are designated $R_{\Delta X}$, $R_{\Delta Y}$, and R_{Θ}.

These calculated advanced parameters are now evaluated to determine if unacceptable misregistrations exist and to indicate the probable causes of such misregistrations. Once $\{\overline{\Delta X}, \overline{\Delta Y}, \overline{\Theta}\}$ and $\{R_{\Delta X}, R_{\Delta Y}, R_{\Theta}\}$ have all been caclulated, their values are automatically compared to statistically determined thresholds called "control limits... All six of these values are automatically displayed to the operator, along with their control limits; values outside these limits are automatically flagged as "bad".

Advanced parameters computed from the material deformati n primary parameters (ε_X, ε_Y, γ_{XY}, α, β) are derived as per instructions of the block 1311. Th advanced parameters $\overline{\varepsilon_X}$, $\overline{\varepsilon_Y}$, $\overline{\gamma_{XY}}$, $\overline{\alpha}$ and $\overline{\beta}$ are calculated by determining th av rage values of ε_X ε_Y γ_{XY}, α and β respectively. The advanced parameters $R_{\varepsilon X}$,

$R_{\varepsilon Y}$, $R_{\gamma XY}$, R_α and R_β, the lot ranges of the primary patterns, are th n calculated as per th instrctions of th bl ck 1313.

Th decision process of block 1317 investigates of the average values of $\overline{\Delta X}$, $\overline{\Delta Y}$ and $\overline{\Theta}$ exceed control limits; these limits may be selected or calculated from prior data. If these control limits are exceeded, an unacceptable registration condition has been detected. Setup error, representing repeatable hardware and/or procedural problems, is investigated as a probable cause according to the instructions of block 1319. This probable cause is listed, as per the instructions of block 1321, and corrective action concerning procedures and hardware corrections is suggested. In photoprint operations, for example, one possible cause of setup error would be inaccurate tooling holes in the phototool; this contribution can be accurately determined by (re)measuring the phototool.

The process flow proceeds to the decision of block 1323 which determines if the lot ranges $R_{\Delta X}$, $R_{\Delta Y}$ and R_Θ exceed the control limits; these limits may be selected or calculated from prior data. If these control limits are exceeded, the flow proceeds to block 1325 whose instructions evaluate the data for probable tooling error. Its causes may be incorrect installation and/or slack in the panel or phototool positioning apparatus. These items are then subjected to mechanical inspection by personnel, as per the probable causes listed, in response to the instructions of the block 1327.

The calculated advanced parameters are evalued to determine if unacceptable conditions of material deformations exist and to indicate the probable causes of such deformations. Once $\{\overline{\varepsilon_X}, \overline{\varepsilon_Y}, \overline{\gamma_{XY}}, \overline{\alpha}, \overline{\beta}\}$ and $\{R_{\varepsilon X}, R_{\varepsilon Y}, R_{\gamma XY}, R_\alpha, R_\beta\}$ have all been calculated, their values are automatically compared to statistically determined thresholds, as described below. Values outside these limits are automatically displayed.

Process flow proceeds to the decision block 1329 to determine of any of the advanced parameter values representing average material deformations $(\overline{\varepsilon_X}, \overline{\varepsilon_Y}, \overline{\gamma_{XY}}, \overline{\alpha}, \overline{\beta})$) exceed their control limits which may be calculated or pre-selected. If these limits are exceeded, the flow proceeds to the instructions of the block 1331 to evaluate for average deformation error. Causes include non-standard environmental conditions of the phototool, panel product or processing machine(s). These probable causes are listed as per the instructions of block 1332 and the flow proceeds to the decision block 1335 which compares the lot ranges { $R_{\varepsilon X}$, $R_{\varepsilon Y}$, $R_{\gamma XY}$, R_α , R_β } with their calculated or pre-established control limits. If these control limits are xceeded, the instructions f the block 1337 valuate th causes f r random deformation rror, such rapidy changing nvironmental conditions (.g. temperature and humidity) during the panel processing procedure.

Long term trend analysis is based on collected data for a plurality of l t samples. Long term trend analysis allows evaluation and fine-tuning of all the registration processes; it is performed according to the flow process disclosed in FIG. 15. Using data from many lots enhances the statistical accuracy of the diagnostics, and facilitates identification of gradual variations and small but statistically significant biases.

Displacement measurements stored from a plurality of lot samples is accumulated according to the instructions of the block 1503. If desired, the data can be sorted to select or eliminate lots according to desired combinations of various criteria, e.g. product family (Double-Sided vs Multilayer) using the menu-driven instructions of block 1505. Extended period parameters are calculated for the accumulated data as per the instructions of block 1507. These values fall into three basic types for each of the eight primary parameters, e.g. ΔX. Ensemble averages, e.g. $\overline{\overline{\Delta X}}$, show any long term average bias. Ensemble standard deviations of lot averages, e.g. $\sigma_{\overline{\Delta X}}$, represent the standard deviations of averages within a lot, and show any long term viability between lots. Ensemble averages of lot standard deviations, e.g. $\overline{\sigma_{\Delta X}}$, show the average viability within lots, averaged over many lots. The calculated results are saved in a file, both human and machine readable, by the instructions in block 1509.

The multiple lot parameters calculated in block 1507 are comared to control limits by the process of decision block 1511. If any of these limits are exceeded, the relavent parameters and their control limits are listed, along with probable causes of error, as per the instructions of block 1515. The ensemble averages for the rigid body parameters {ΔX, ΔY, Θ} (e.g. $\overline{\overline{\Delta X}}$), and their ensemble averages of lot standard deviations (e.g. $\overline{\sigma_{\Delta X}}$) have causes including but not limited to those listed by blocks 1321 and 1327 respectively. The ensemble averages for the material deformations {ε_X, ε_Y, γ_{XY}, α, β} (e.g. $\overline{\overline{\varepsilon_X}}$) and their ensemble averages of lot standard deviations (e.g. $\overline{\sigma_{\varepsilon X}}$) have causes including but not limited to those listaed by block 1333 and 1339 respectively. Results of the long term trend analysis are recorded and summarized, as per block 1515, and displayed as per block 1519.

A measurement system suitable for use in the described metrology system described herein is shown schematically in FIG. 16. A transparent reference plate 1610 with reference fiducials 1611-1614 in the four corners is mounted above four video cameras 1621-1624 with the fiducials in their field of vision. The pattern 1630 includes its own complementary fiducials 1631-1634 located in its corners. The fiducials 1631-1634 are measured with respect to the fiducials 1611-1614 of the reference plate to determin th U and V displacements. For measurem nt n pattern 1630 is ov rlaid on top of the reference plate 1610 and positioned by application of th method disclosed in

the aforementioned 4,793,052 patent. Engaging elem nts 1691-1694 controlled by a mechanism such as disclosed in th (052) patent engage holes punched r drilled in the pattern and postion it so that its center and an axis through that center is congruent with a center of the reference plate and an axis passing through that center. Details of the positioning mechanism and the operation there of may be obtained from the (052) patent whose teaching and disclosure is incorporated herein by reference.

The displacements of the pattern fiducials from the reference fiducials are measured by a computer control system 1650 from the video images produced by the camera 1621-1624. The computer control system 1650 includes input means 1651 for collecting the measured fiducial displacements and a control terminal 1652 for accepting operator input. A display terminal 1653 is included for displaying basic measurements, calculated results and graphical depiction thereof. A bus 1655 interconnects these units to each other and to a processor 1656, a stored program unit 1657 and a memory unit 1658.

Claims

1. Apparatus for analyzing pattern registration in a panel manufacturing process, comprising:

   a panel locating mechanism using panel centered positioning techniques;

   a pattern marking corners of the patterns with working fiducials symmetric about a center of the pattern;

   a transparent reference surface with reference fiducials marked on the surface and positioned symmetric about a center of the reference surface;

   superimposing a pattern, with corners of the pattern marked with working fiducials symmetric about a center of the pattern, on the reference surface using the panel locating mechanism for positioning the pattern on the reference surface;

   CHARACTERIZED BY:

   a machine vision measurement apparatus (1610) positioned for measuring displacements of the working fiducials from the reference fiducials;

   a computer system (1650) coupled to receive the measured displacements from the machine vision measurement apparatus and including memory for storing the measured displacements in a data base;

   the computer system including (1657) a stored program control including instructi ns for d composing the measured displacem nts stored in th data base into a s t of rigid body transiti n param ters and material d f rmati n transiti n parameters;

   th stored program control f the computer system including further instructi ns for transforming th rigid body parameters and material deformation parameters, associated with a plurality of patterns of a sample lot being analyzed, into a set of multiple composite distortion parameters related to a plurality of patterns, including average values and deviation values of the rigid body parameters and average values and deviation values of the material deformation parameters;

   the computer system including memory (1658) including stored numerical control limits for each of the multiple composite distortion parameters;

   the stored program control including further instructions for comparing each of the multiple composite distortion parameters with the numerical control limits;

   the stored program control including instructions for assigning causes of misregistration to specific operations and conditions of the panel manufacturing process in response to the multiple composite distortion parameters that exceed the critical threshold limits; and

   the computer system including information output display apparatus (1653) for communicating the assigned causes to operative personal.

2. Apparatus for analyzing pattern registration as claimed in claim 1;

   FURTHER CHARACTERIZED BY:

   the stored program being operative for decomposing the measured displacements into rigid body and deformation parameters by solving polynomial expansion series equations.

3. Apparatus for analyzing pattern registration as claimed in claim 2;

   FURTHER CHARACTERIZED BY:

   memory for storing measured displacements from data of an aggregate of sample lots; and the stored program control being operative for converting the measured displacements from data of an aggregate of sample lots into extended period parameters for analyzing trends of registration in the panel manufacturing process.

4. A method for analyzing pattern registration in a panel manufacturing process;

   comprising the steps of:

   using panel centered registration patterns in the manufacturing process;

   marking corners of the patterns with working fiducials symm tric about a center of th pattern;

   marking corners of a ref rence surface with reference fiducials symmetric about a center

of the reference surface;

superimposing the pattern n th ref r- nce surface using panel centered positioning techniques and measuring displacem nts of the working fiducials from the reference fiducials;

CHARACTERISED BY:

storing the measured displacements in a data base and utilizing a stored program control for decomposing the measured displacements into a set of rigid body parameters and material deformation parameters;

utilizing the stored program control for transforming rigid body parameters and material deformation parameters, associated with a plurality of patterns of a sample lot being analyzed, into a set of multiple composite distortion parameters related to a plurality of patterns, including average values and deviation values of the rigid body parameters and average values and deviation values of the material deformation parameters;

utilizing the stored program control for comparing each of the multiple composite distortion parameters with critical threshold limits;

utilizing the stored program control for assigning causes of misregistration to specific operations and conditions of the panel manufacturing process in response to the multiple composite distortion parameters that exceed the critical threshold limits.

5. A method for analyzing pattern registration as claim in claim 4;

FURTHER CHARACTERIZED BY THE STEPS OF:

decomposing the measured displacements into rigid body and deformation parameters by having the stored program control solve polynomial expansion series equations.

6. A method for analyzing pattern registration as claimed in claim 5;

FURTHER CHARACTERIZED BY THE STEPS OF:

utilizing the stored program control for converting the measured displacements from data of an aggregate of sample lots into extended period parameters for analyzing trends of registration in the panel manufacturing process.

7. A method for analyzing pattern registration as claimed in claim 4;

FURTHER CHARACTERIZED BY THE STEPS OF:

utilizing the stored program for computati n of control limits using th stored measured displacements from prior measur m nts in previous sample measurements.

FIG. 1

ΔX: HORIZONTAL DISPLACEMENT

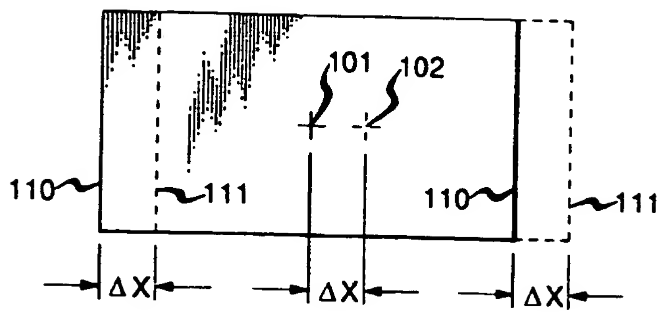


FIG. 2

ΔY: VERTICAL DISPLACEMENT

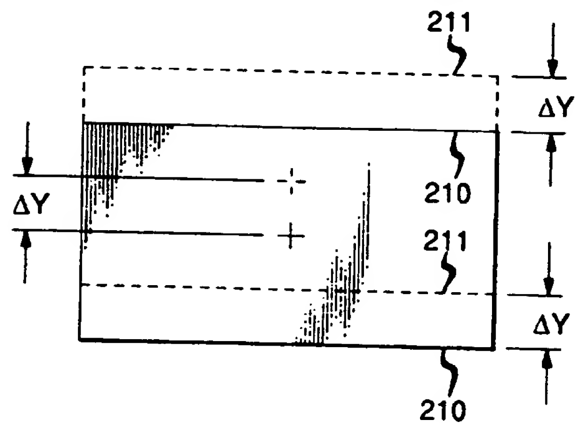


FIG. 3

θ: ROTATION

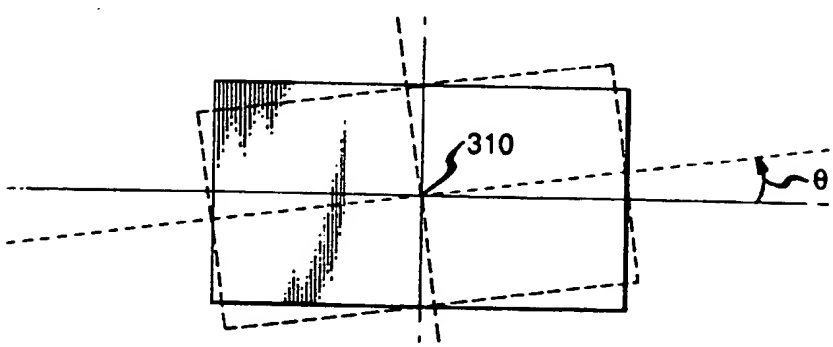


FIG. 4

α DISTORTION

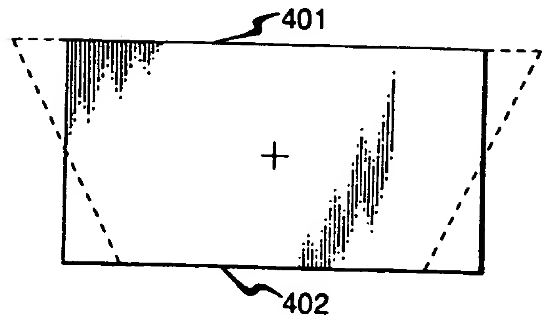


FIG. 5

β DISTORTION

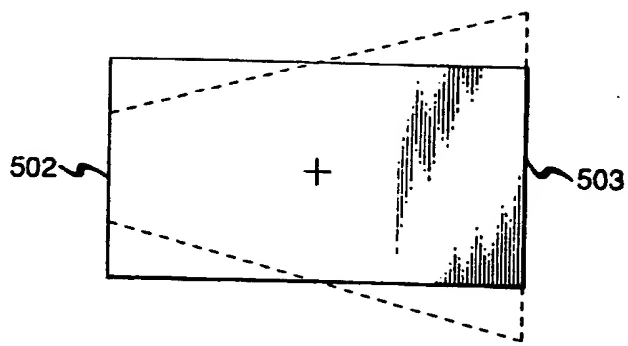


FIG. 6

γ_{XY}: SHEAR

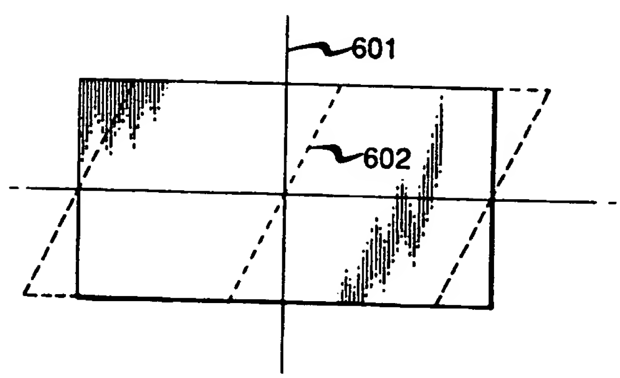


FIG. 7

ε_X: X EXPANSION

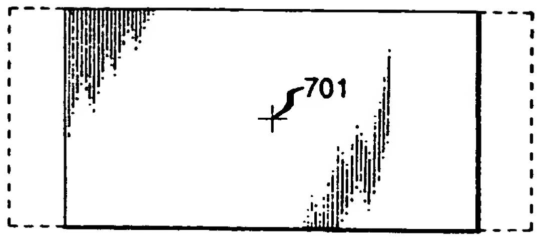


FIG. 8

ε_Y: Y EXPANSION

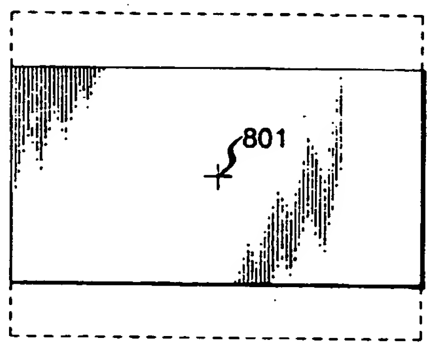


FIG. 9

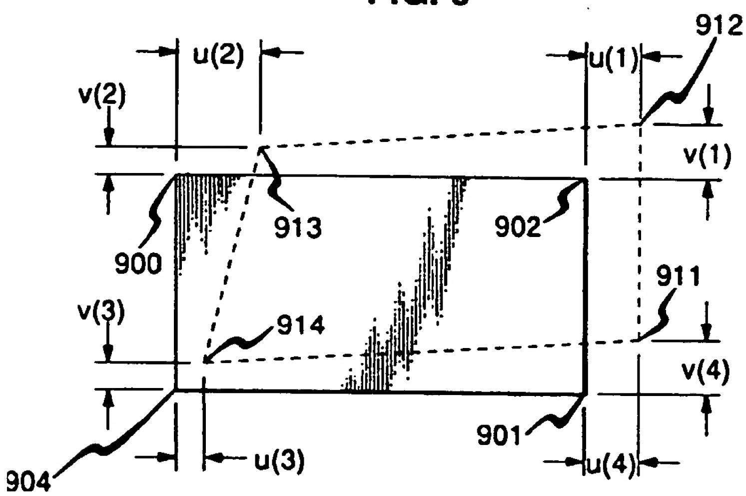


FIG. 10

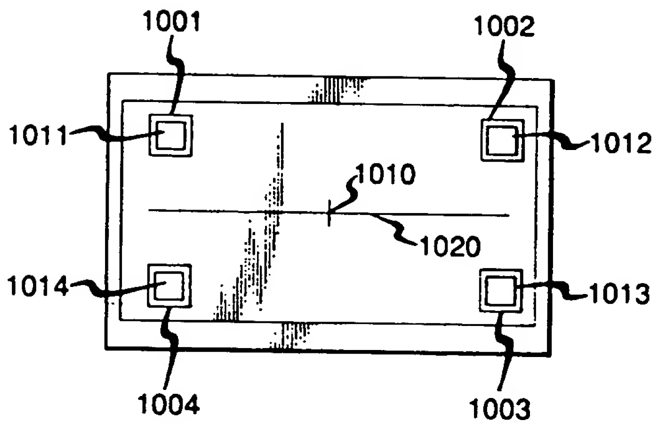

1001
1002
1011
1012
1010
1020
1014
1013
1004
1003

FIG. 11

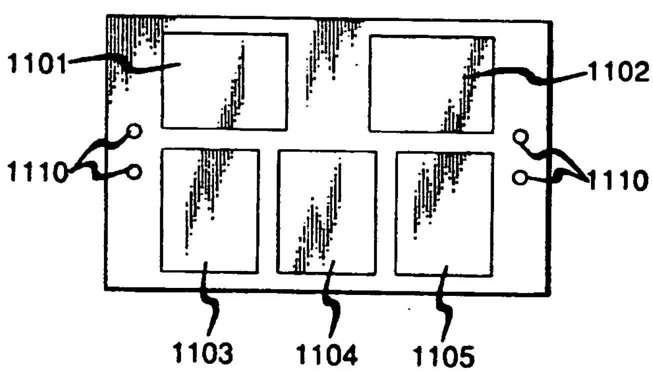

1101
1102
1110
1110
1103
1104
1105

FIG. 12

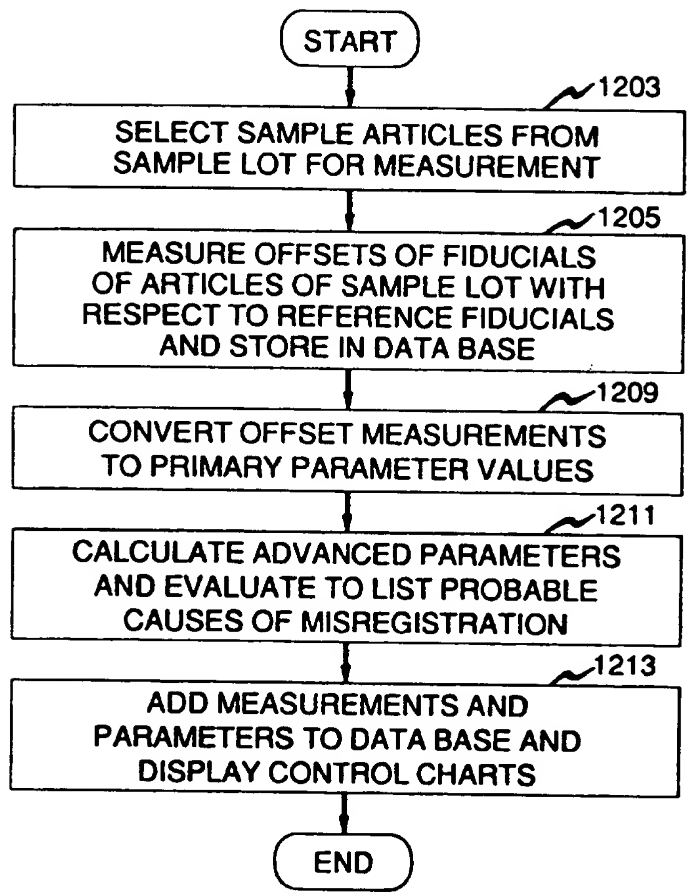

START
1203
SELECT SAMPLE ARTICLES FROM SAMPLE LOT FOR MEASUREMENT
1205
MEASURE OFFSETS OF FIDUCIALS OF ARTICLES OF SAMPLE LOT WITH RESPECT TO REFERENCE FIDUCIALS AND STORE IN DATA BASE
1209
CONVERT OFFSET MEASUREMENTS TO PRIMARY PARAMETER VALUES
1211
CALCULATE ADVANCED PARAMETERS AND EVALUATE TO LIST PROBABLE CAUSES OF MISREGISTRATION
1213
ADD MEASUREMENTS AND PARAMETERS TO DATA BASE AND DISPLAY CONTROL CHARTS
END

FIG. 13

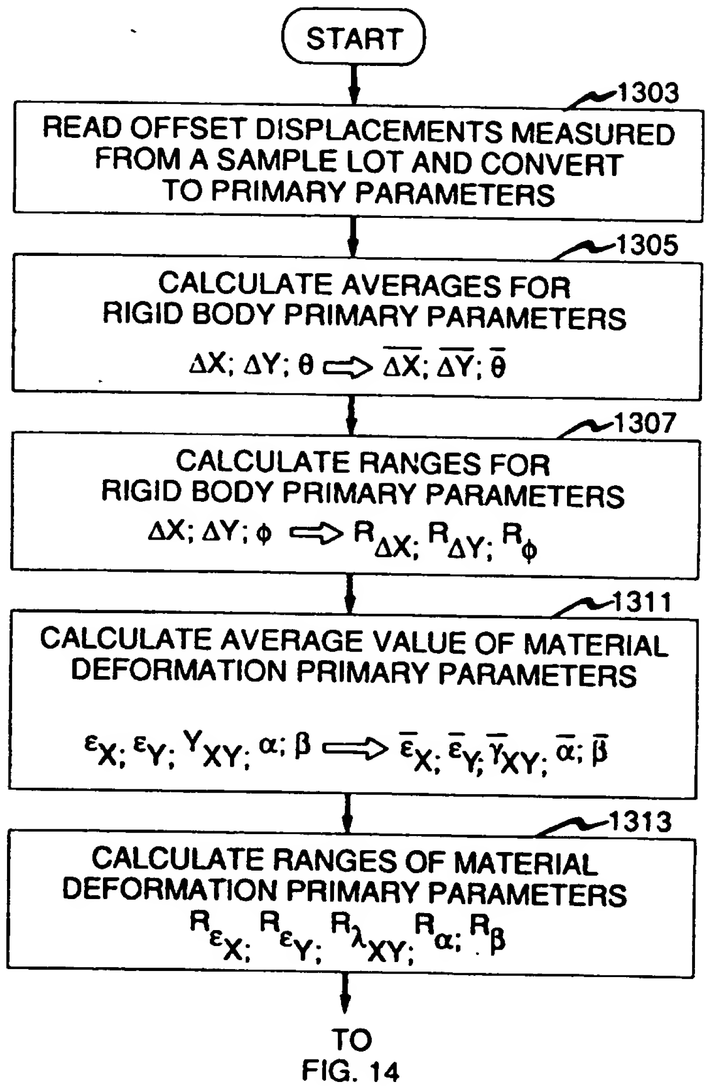

START
1303
READ OFFSET DISPLACEMENTS MEASURED FROM A SAMPLE LOT AND CONVERT TO PRIMARY PARAMETERS
1305
CALCULATE AVERAGES FOR RIGID BODY PRIMARY PARAMETERS
$\Delta X; \Delta Y; \theta \Rightarrow \overline{\Delta X}; \overline{\Delta Y}; \bar{\theta}$
1307
CALCULATE RANGES FOR RIGID BODY PRIMARY PARAMETERS
$\Delta X; \Delta Y; \phi \Rightarrow R_{\Delta X}; R_{\Delta Y}; R_{\phi}$
1311
CALCULATE AVERAGE VALUE OF MATERIAL DEFORMATION PRIMARY PARAMETERS
$\varepsilon_X; \varepsilon_Y; \gamma_{XY}; \alpha; \beta \Rightarrow \bar{\varepsilon}_X; \bar{\varepsilon}_Y; \bar{\gamma}_{XY}; \bar{\alpha}; \bar{\beta}$
1313
CALCULATE RANGES OF MATERIAL DEFORMATION PRIMARY PARAMETERS
$R_{\varepsilon_X}; R_{\varepsilon_Y}; R_{\lambda_{XY}}; R_{\alpha}; R_{\beta}$
TO FIG. 14

FIG. 14

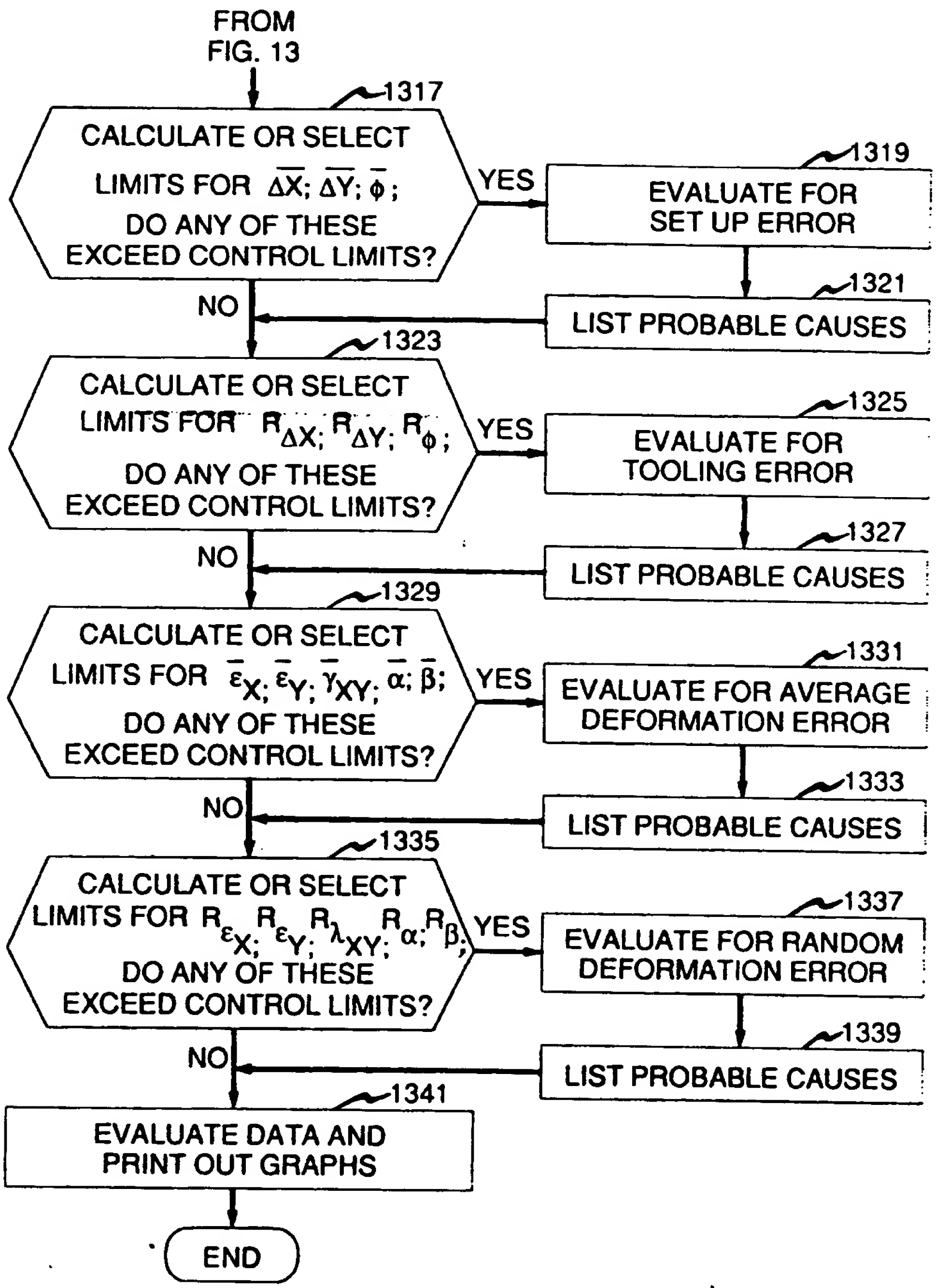

FROM
FIG. 13
1317
CALCULATE OR SELECT LIMITS FOR $\overline{\Delta X}$; $\overline{\Delta Y}$; $\overline{\phi}$; DO ANY OF THESE EXCEED CONTROL LIMITS?
YES
1319
EVALUATE FOR SET UP ERROR
1321
LIST PROBABLE CAUSES
NO
1323
CALCULATE OR SELECT LIMITS FOR $R_{\Delta X}$; $R_{\Delta Y}$; R_{ϕ}; DO ANY OF THESE EXCEED CONTROL LIMITS?
YES
1325
EVALUATE FOR TOOLING ERROR
1327
LIST PROBABLE CAUSES
NO
1329
CALCULATE OR SELECT LIMITS FOR $\overline{\varepsilon}_X$; $\overline{\varepsilon}_Y$; $\overline{\gamma}_{XY}$; $\overline{\alpha}$; $\overline{\beta}$; DO ANY OF THESE EXCEED CONTROL LIMITS?
YES
1331
EVALUATE FOR AVERAGE DEFORMATION ERROR
1333
LIST PROBABLE CAUSES
NO
1335
CALCULATE OR SELECT LIMITS FOR R_{ε_X}; R_{ε_Y}; $R_{\lambda_{XY}}$; R_{α}; R_{β}; DO ANY OF THESE EXCEED CONTROL LIMITS?
YES
1337
EVALUATE FOR RANDOM DEFORMATION ERROR
1339
LIST PROBABLE CAUSES
NO
1341
EVALUATE DATA AND PRINT OUT GRAPHS
END

FIG. 15

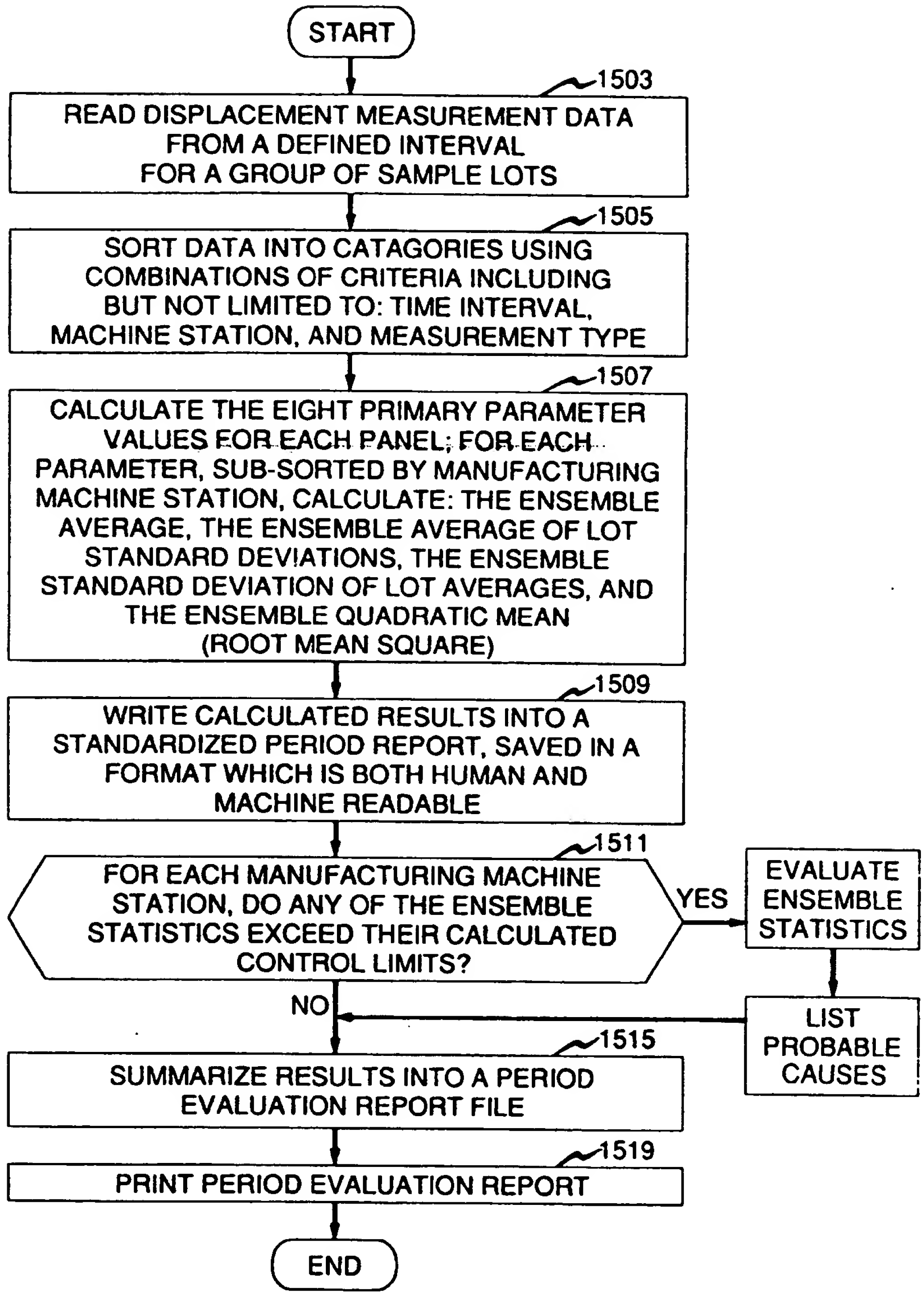
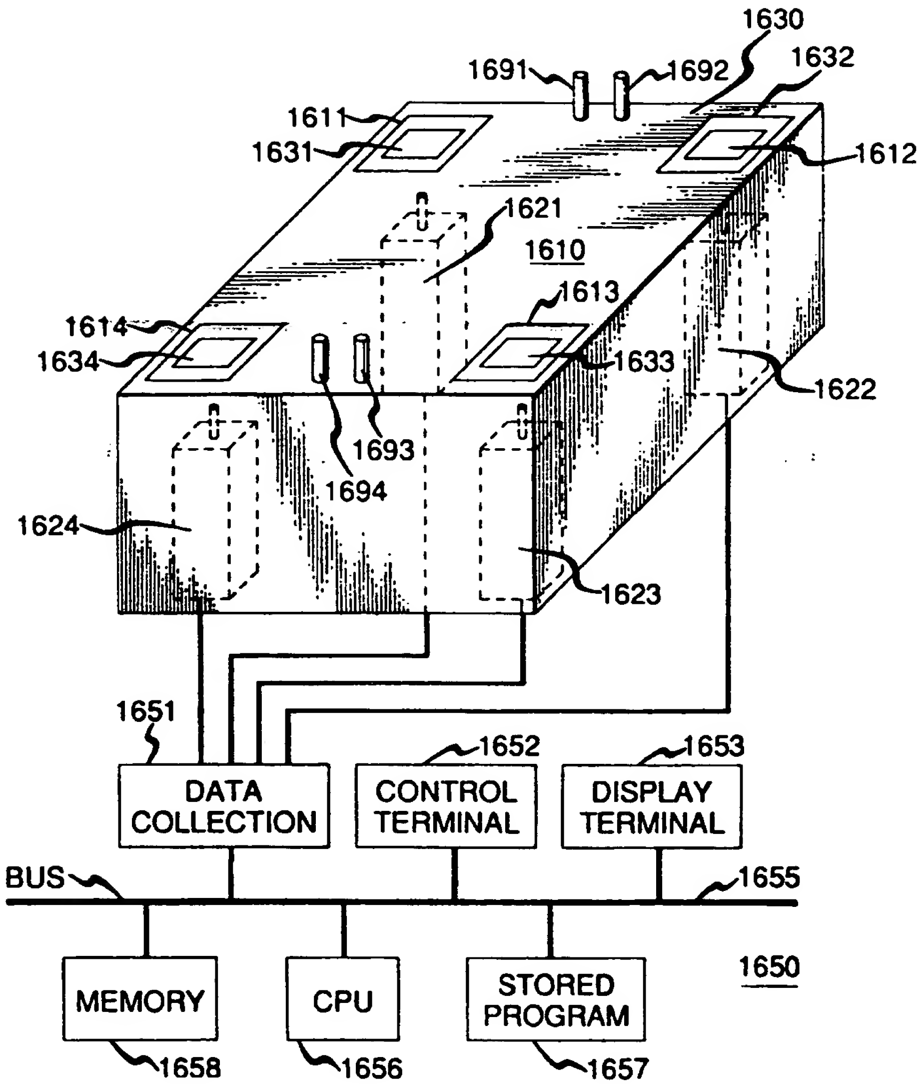

START
1503
READ DISPLACEMENT MEASUREMENT DATA FROM A DEFINED INTERVAL FOR A GROUP OF SAMPLE LOTS
1505
SORT DATA INTO CATAGORIES USING COMBINATIONS OF CRITERIA INCLUDING BUT NOT LIMITED TO: TIME INTERVAL, MACHINE STATION, AND MEASUREMENT TYPE
1507
CALCULATE THE EIGHT PRIMARY PARAMETER VALUES FOR EACH PANEL; FOR EACH PARAMETER, SUB-SORTED BY MANUFACTURING MACHINE STATION, CALCULATE: THE ENSEMBLE AVERAGE, THE ENSEMBLE AVERAGE OF LOT STANDARD DEVIATIONS, THE ENSEMBLE STANDARD DEVIATION OF LOT AVERAGES, AND THE ENSEMBLE QUADRATIC MEAN (ROOT MEAN SQUARE)
1509
WRITE CALCULATED RESULTS INTO A STANDARDIZED PERIOD REPORT, SAVED IN A FORMAT WHICH IS BOTH HUMAN AND MACHINE READABLE
1511
FOR EACH MANUFACTURING MACHINE STATION, DO ANY OF THE ENSEMBLE STATISTICS EXCEED THEIR CALCULATED CONTROL LIMITS?
YES
EVALUATE ENSEMBLE STATISTICS
LIST PROBABLE CAUSES
NO
1515
SUMMARIZE RESULTS INTO A PERIOD EVALUATION REPORT FILE
1519
PRINT PERIOD EVALUATION REPORT
END

FIG. 16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DATA COLLECTION
CONTROL TERMINAL
DISPLAY TERMINAL
BUS
1655
1650
MEMORY
CPU
STORED PROGRAM
1658
1656
1657